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**THE ABM TREATY AND
NATIONAL BALLISTIC
MISSILE DEFENSE
OPPORTUNITIES**

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MAY, 1996

R-117-ACDA

Preface

The purpose of this report is to provide an examination of the potential capabilities of ballistic missile defense systems that comply with the ABM Treaty. Secondly, this report presents methods of analyzing the effects and consequences of various doctrines for allocating ballistic missile defense interceptors against attacks from major protagonists of the United States, or attacks that might be prosecuted by third world nations. Originally, the intent of this report was to assemble and consolidate notes on ballistic missile defenses gathered by the author. As the report took form, however, it seemed more appropriate to provide its contents to a larger audience.

This report should be of interest to personnel within the arms control and defense communities, as well as to others concerned with issues related to ballistic missile defense. The present report is but one part of an overall project concerned with theater and national ballistic missile defenses, their possible effectiveness, and related arms control issues.

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None of the material contained in this report should be construed to represent the official views of the U.S. Arms Control and Disarmament Agency, the U.S. Department of Defense, or any other governmental organization. The views are solely those of the author. If readers have suggestions which might augment the extent of these analyses, or have comments on the material contained in this report, they are encouraged to contact the author.

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I - INTRODUCTION

The purpose of this report is to provide insights into the potential capabilities of future ballistic missile defense systems that could comply with the terms of the ABM Treaty. The first step toward this end is to provide analyses of the allocation of defense interceptors and the effects of different allocation schemes for countering attacks by re-entry vehicles (RVs) delivered by ballistic missiles. Applications of the analysis methods will provide some bounds on possible defensive actions to counter ballistic missile attacks without violating the terms of the ABM Treaty. The issue of expanding future ballistic missile defenses beyond the bounds agreed to by the U.S. and Russia may be of concern to some readers. These concerns are addressed in later parts of this report.

Methods of analyzing interceptor allocation are presented in Chapter II. Defense dominant situations include conditions where the number of interceptors is greater than or equal to the number of RVs. In some cases, the number of re-entering objects may outnumber the defensive interceptors. Under conditions where the defensive firepower may dominate, examinations are directed at the uniform allocation of interceptors, or alternatively, employment of a shoot-look-shoot doctrine. Shoot-look-shoot doctrines may have some variations, and these are examined.

Limited ballistic missile attacks are examined in Chapter III. In this report, limited attacks are those where the number of re-entering objects are less than the number of defensive interceptors. The focus of this chapter will be on countering limited attacks with 100 or fewer interceptors.

Larger ballistic missile attacks will be considered in some detail in Chapter IV. Cases involving only RVs, or a mixture of RVs and accompanying decoys will be considered. Increases in the level of defense and the effect of decoys to offset such increases will be examined.

Finally, a summary and some implications for future national ballistic missile defense concepts of the U.S. are presented in Chapter V of this report. References follow this chapter.

II - INTERCEPTOR ALLOCATION METHODS

The purpose of this chapter is to outline methods and formulae for allocating ballistic missile defense interceptors to counter attacking re-entry vehicles (RVs). Not all allocation techniques may appear optimal to some readers, but they are included in an attempt to be nearly complete.

As a first approach, the defense could uniformly allocate all available interceptors against incoming RVs. The defense could be forced to adopt this allocation if battle space or time for defense operations were limited.

Shoot-look-shoot campaigns may be possible if battle space can be provided by systems which warn of ballistic missile attacks. Sensor systems could provide initial warning, and perhaps, preliminary tracking data. No evaluation of the performance of such systems is provided here. It is assumed that such capabilities would support limited two-round shoot-look-shoot campaigns. A few variations on such campaigns will be examined.

If the defense objective is to completely block ballistic missile attacks, how many interceptors and what performance would be needed? Absolute assurance that no RVs would penetrate the defense may not be possible. Setting an objective in terms of assuring a high probability that no RVs will leak through the defense system will be examined. This examination leads to one other variation for allocating interceptors.

For protection against small attacks, defense dominance is assumed. Under this assumption, the number of available interceptors is greater than the number of attacking RVs. If the number of attacking RVs is greater than the number of interceptors, then all of the allocations examined in this chapter degenerate into a so-called subtractive defense mode of operation. In a later chapter, the contrast between a pure subtractive defense and a mode of adaptive preferential defense will be discussed.

UNIFORM ALLOCATION

The uniform allocation of interceptors is often defined as a continuous function. The probability of RVs penetrating the defense under these conditions is defined as

$$1) P(\text{pen}) = (1-k)^{(I/RV)}$$

where $P(\text{pen})$ is the probability of penetration, k is the single shot probability of kill of an interceptor, I is the number of interceptors, and RV is the number of RVs brought under fire. This equation is valid only when the ratio I/RV is integer. When this ratio has a fractional part, the allocation is not strictly uniform since some RVs will be targeted by one more interceptor than others. Under these conditions, the function is continuous, but the first derivative is not.

$$2) P(\text{pen}) = [1-fp(I/RV)] \cdot (1-k)^{\text{INT}(I/RV)} + fp(I/RV) \cdot (1-k)^{\text{INT}(I/RV+1)} \\ = P(I, RV, k)$$

In this notation $fp(x)$ represents the fractional part of x , and $\text{INT}(x)$ represents the integer part of x . The function consists of straight line segments connecting the points where the ratio I/RV is integer, as illustrated in Figure 1. The figure shows the penetration probability as a function of I/RV with the single shot probability of kill as a parameter. If there is not enough battle space to conduct shoot-look-shoot campaigns, or the

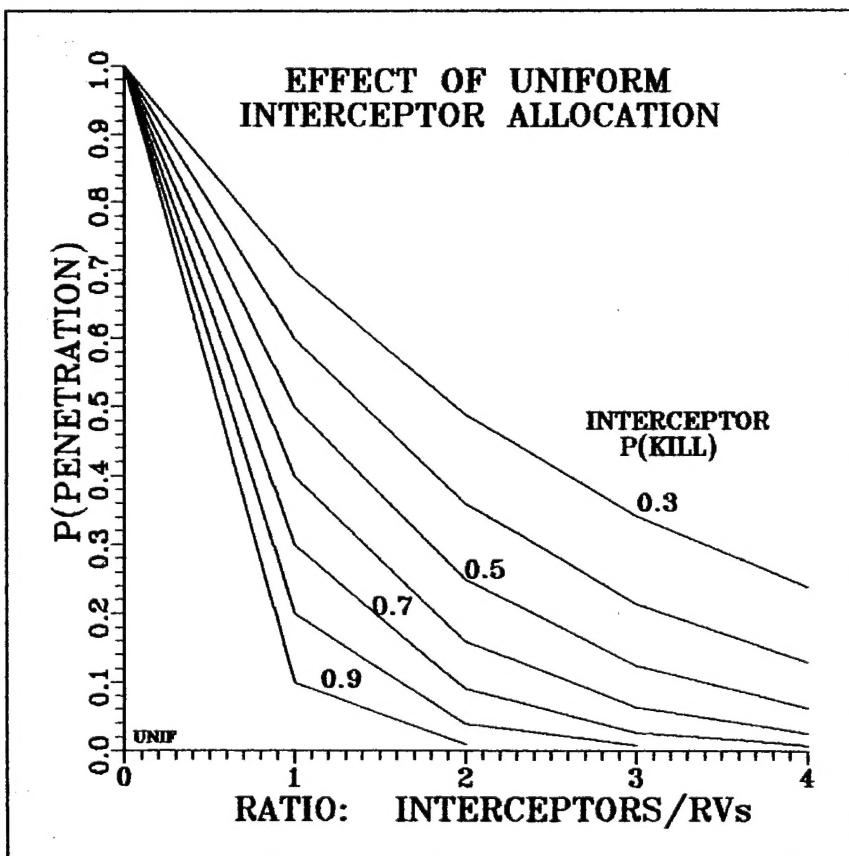


Figure 1

interceptor battery commander believes that there is not enough battle space, then the uniform allocation would be used. When the number of RVs is greater than the number of available interceptors, then the uniform allocation degenerates into a subtractive defense,

$$3) P(\text{pen}) = 1 - k \cdot I / RV, \quad RV >= I.$$

SHOOT-LOOK-SHOOT ALLOCATIONS

The battery commander or his superiors may choose to conduct a shoot-look-shoot campaign against the RVs, if they believe that there is enough battle space for such operations. In this analysis, three variations of shoot-look-shoot are considered.

Shoot-Look-Shoot All

The first variation is labeled SLS-ALL. In this variation, one interceptor is fired against each RV in a first round. Sensors then determine which RVs have survived, and all of the remaining interceptors are then fired against the surviving RVs on the second round. For this examination, the sensors, their supporting systems, and data correlation techniques are assumed to be perfect and timely in determining which RVs survive. Residual interceptors are allocated uniformly against the survivors.

In the first round, some RVs will survive. The number of survivors is dependent on the number of RVs (RV) and the single shot probability of the interceptors (k). The number of survivors is simply $RV \cdot (1-k)$, and the defender knows exactly which RVs these are. In the second round, all remaining interceptors are committed uniformly to the survivors. The remaining interceptors for the second round are $I - RV$. The probability that RVs will penetrate the defense is given by

$$3) P(\text{pen}) = (1-k) \cdot P[I - RV, RV \cdot (1-k), k]$$

where the second term of this expression is that already displayed above in equation 2. More explicitly, the probability of RV penetration becomes

$$4) P(\text{pen}) = (1-k) \cdot \{ [1 - fp(G)] \cdot (1-k)^{\text{INT}(G)} + fp(G) \cdot (1-k)^{\text{INT}(G+1)} \}$$

where $G = (I/RV - 1)/(1-k)$. Under this firing doctrine, all available interceptors will be committed. As a result, this firing doctrine is based on the crucial assumption that all of the attacker's RVs have been committed and that there will be no follow-on ballistic missile attacks.

Shoot-Look-Shoot One

A second variation to shoot-look-shoot firing doctrines is labeled SLS-ONE. Under this option, the battery commander elects to fire one interceptor against each incoming RV on the first round, assess which RVs survive, and then commit one interceptor against each surviving RV. The object of this doctrine is to try to save some interceptors in case another unexpected wave of RVs appears before any reload operations can be conducted.

As in the SLS-ALL doctrine, the number of RVs surviving the first round is $RV \cdot (1-k)$. On the second round, one interceptor is fired against each surviving RV provided there are enough interceptors available to perform a full second round. Under these conditions, the probability of RV survival is

$$5) P(\text{pen}) = (1-k)^2, \text{ if } RV \leq I/(2-k)$$

If the number of residual interceptors from the first round is insufficient to fire one interceptor against each surviving RV, then the overall penetration probability becomes

$$6) P(\text{pen}) = 1 - k \cdot I/RV, \text{ if } RV > I/(2-k).$$

With this firing doctrine, some interceptors can be saved as a reserve for follow-on attacks. If the first round of attack is limited so that $RV < I/(2-k)$, then the number of interceptors kept in a reserve would amount to $I - RV \cdot (2-k)$, and the total number of interceptors committed would be $RV \cdot (2-k)$. If the number of RVs in the first attack is large, $RV \geq I/(2-k)$, then no interceptors could be placed in a reserve -- all of them would be expended in countering the attack.

Shoot-Look-Shoot Two

A third variation of the shoot-look-shoot firing doctrine is labeled SLS-TWO. Under this doctrine, the RVs surviving from the first round would be countered by firing two interceptors. While fewer interceptors might be saved compared to the SLS-ONE doctrine, the probability of penetration of the RVs would be less than in the SLS-ONE doctrine.

The probability of RV penetration under this firing doctrine would be

$$7) P(\text{pen}) = (1-k)^3, \text{ if } RV \leq I/(3-2 \cdot k)$$

or

$$8) P(\text{pen}) = 1 - k \cdot I/RV \text{ if } RV > I/(3-2 \cdot k).$$

The number of interceptors fired during this campaign would be $RV \cdot (3-2 \cdot k)$ so long as this amount is less than the interceptor stockpile. Otherwise, all interceptors would be expended.

CONFIDENCE ESTIMATES FOR BLOCKING ATTACKS

In some cases, decision makers will want to know if the ballistic missile defense system can completely block small attacks. It is not possible to have an absolute assurance that no RVs will leak through the defense. In this analysis, we will specify some high probability that no RVs will penetrate the defense. This probability is a confidence level, labeled CL. It is a function of the probability of penetration of the RVs, $P(\text{pen})$. The binomial distribution is calculated for the number of penetrating RVs, assuming that intercept trials are independent. The probability that there are no leakers is then set to some confidence level. In general

$$9) \quad CL = [1 - P(\text{pen})]^{RV}$$

where $P(\text{pen})$ is the penetration probability for either the uniform allocation of all interceptors, or shoot-look-shoot campaigns where all interceptors are expended against the attacking objects. Solving this equation will lead to the determination of the interceptors needed to block attacks at some specified confidence level for a given attack size (RV). Later, some examples will be presented assuming that $CL = 0.95$ for various values of single shot probability of interceptor kill.

The estimation of confidence levels suggests a further firing doctrine labeled SLS-SOME. Under this doctrine, the number of interceptors committed in a shoot-look-shoot campaign would be determined by the confidence level specified ahead of time. In many cases, not all of the interceptors would be committed, particularly if the attack were small. The first round would consist of committing one interceptor to counter each RV. On the second round, enough interceptors would be committed against each RV surviving the first round to insure that the probability of no RVs leaking through the defense would meet some level specified by national leadership or at some lower level. For example, the Joint Staff may recommend the probability of no RVs leaking through the ballistic missile defenses should be set to 0.95, and National Command Authority might agree.

SUMMARY

Applications of each firing doctrine and these equations will be presented later. All of the above interceptor commitment doctrines are based on the assumption that the defender either has no time available to conduct a shoot-look-shoot campaign and

must use a uniform allocation of interceptors, or the defender has enough time to conduct a two round shoot-look-shoot campaign, but no more. A three or four round campaign would substantially reduce the probability of RV penetration if the interceptors greatly outnumber the attacking RVs. In such multi-phase campaigns the number of interceptors committed to achieve some confidence level of no RVs leaking through the defense would be substantially reduced. However, if the battle space is limited, such campaigns might not be feasible. For this reason, the analyses presented in this report are limited to either a single commitment of all interceptors at one time, or a two-round shoot-look-shoot campaign.

III - LIMITED BALLISTIC MISSILE ATTACKS

The purpose of this chapter is to indicate capabilities of a U.S. ballistic missile defense system that conforms with the ABM Treaty. This treaty, as amended, limits the U.S. to one ABM site equipped with 100 or fewer interceptors. With 100 interceptors, what attack size could be negated? The answer to this question depends on the allocation of interceptors, their reach, and their single shot kill probabilities (SSPk).

Different methods of allocating interceptors to counter RVs have been described in a previous chapter. These methods are applied here in relation to 100 interceptors as limited by the ABM Treaty. In this chapter, it is assumed that any attacks by third world nations would be limited. Under this assumption, a stockpile of 100 interceptors would constitute a "defense dominant" environment. Later, larger attack sizes will be examined.

The reach of interceptors is dependent on many factors. The dominant factors include warning time, determination of attacking RV trajectories in time to construct intercept opportunities, and the actual range of the interceptor. Warning of the launch of hostile ballistic missiles might be forthcoming from a boost phase detection system, such as the Defense Support Program (DSP). Midcourse determination of the trajectories of RVs and other objects could be a result of systems which track, assemble data, and construct individual trajectories for each RV. One example of such a system is the Brilliant Eyes constellation of satellites currently in research. Ground based sensor and support systems would also contribute to such efforts.

The probability of each interceptor negating an RV, the single shot probability of kill (SSPk) has not yet been determined within the scope of present U.S. research efforts. For this reason, only postulated examples of SSPk values can be offered here. The reader is cautioned, however, to treat such postulations with a degree of skepticism, since opinions about the effectiveness of many interceptor concepts could vary over wide ranges. In the author's experience, Army field personnel have expressed views that a single shot probability of kill for an air defense system of about 0.3 would exceed all expectations. Air-to-air combat experience has indicated that air-to-air missile SSPk might be somewhat greater than 0.1 (U.S. experience in VietNam) to slightly more than 0.5 (Israeli Air Force in the Yom Kippur War). Developers of various types of interceptor systems sometimes predict an SSPk greater than 0.8. All that this analysis can be expected to show is the relative effect of different allocation firing doctrines, and the conditions under which each policy might be more or less effective in terms of diluting a ballistic missile threat and preserving some sort of reserve in a stockpile limited to 100 interceptors.

The probability that RVs penetrate a ballistic missile defense system is dependent on the single shot probability of kill (SSPk) of the interceptors and the firing doctrine employed by the defender. To illustrate these dependencies, an SSPk = 0.7 has been chosen. Figure 2 indicates the probability of RV penetration as a function of attack size, assuming that the defender has 100 interceptors available. If the defender shoots a single interceptor against each

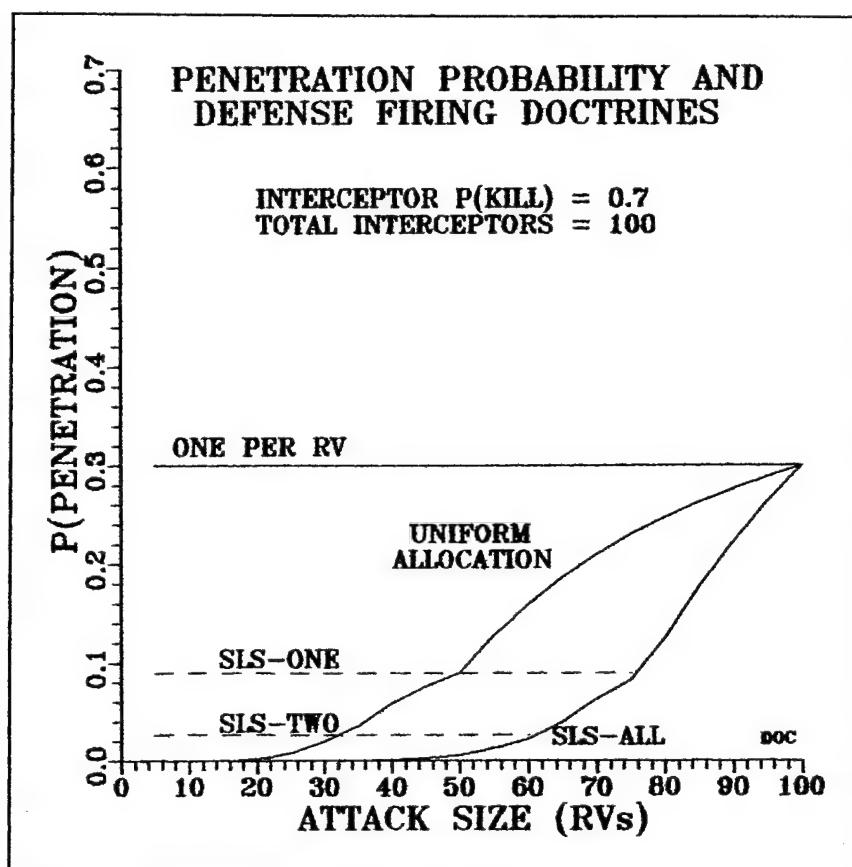


Figure 2

incoming RV, then the expected fraction of RVs penetrating to their targets will be 0.3 or 1-k. In contrast to such a commitment doctrine, the defender may choose to employ a shoot-look-shoot all (SLS-ALL) firing doctrine. On the first round, one interceptor is committed to each RV, then after a perfect assessment of which RVs have survived, the entire remaining stockpile of interceptors is allocated uniformly to the surviving RVs. No interceptors would be reserved for any follow-on attacks. Under these conditions, no RVs would be expected to penetrate for attacks of 40 RVs or less. If there were not enough battle space to conduct a shoot-look-shoot campaign, the defender could choose to uniformly allocate all interceptors against all of the RVs. Under this firing doctrine, no RVs would be expected to penetrate for attacks up to 16 RVs. Intermediate shoot-look-shoot firing doctrines (SLS-ONE or SLS-TWO) could be chosen in an attempt to preserve some of the interceptor stockpile in case there were some follow-on attacks. Under these conditions, the fraction of RVs expected to penetrate would be either 0.09 (SLS-ONE) or 0.027 (SLS-TWO) for limited attacks. If the attack size were less than 76 RVs under the SLS-ONE doctrine, then some interceptors would be saved as a reserve. For attack

sizes less than 60 RVs, then some interceptors could be saved as a reserve under the SLS-TWO firing doctrine.

If the SSPk of the interceptors were less, 0.5, then the same trends would prevail, but the fractions of RVs penetrating would be larger. With a lower SSPk of 0.5, the defense would not be as capable in shutting out as many expected RVs under a SLS-ALL doctrine. These trends are indicated in Figure 3. Depending on whether or not battle space is available, no RVs would be expected to penetrate for attack sizes of 10 or 17 RVs for the uniform allocation or the SLS-ALL, respectively. A substantial fraction of the RVs would be expected to penetrate for the other firing doctrines indicated.

The number of RVs which penetrate a ballistic missile defense may become intolerable to the national leadership, even for small missile attacks. Figure 4 indicates the expected number of RVs penetrating as a function of attack size for the various interceptor commitment doctrines considered in this analysis. If a leader believes that even the explosion of one nuclear weapon on its homeland would be unacceptable, then clearly the commitment of all available interceptors would be needed to thwart such attacks. If the attacks were quite small, between five and ten RVs, then the SLS-TWO doctrine would result in an expected penetration of less than one RV. Would a national leader be assured of the defense effectiveness? What may be needed is to assure a very high probability that no RVs would leak through the defenses.

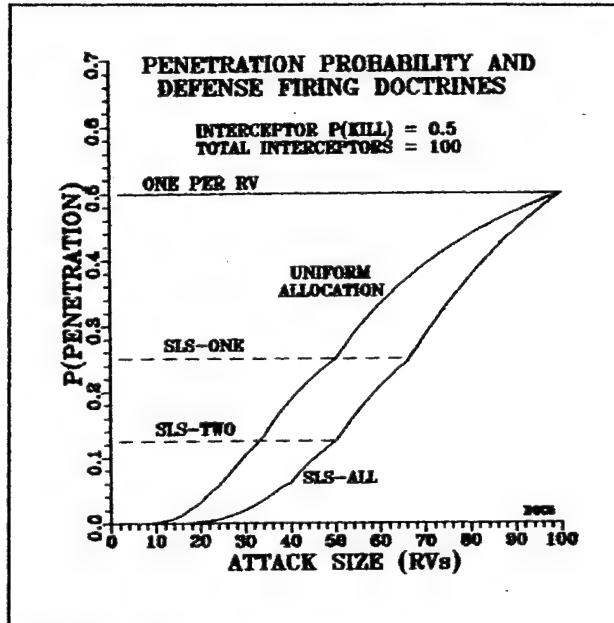


Figure 3

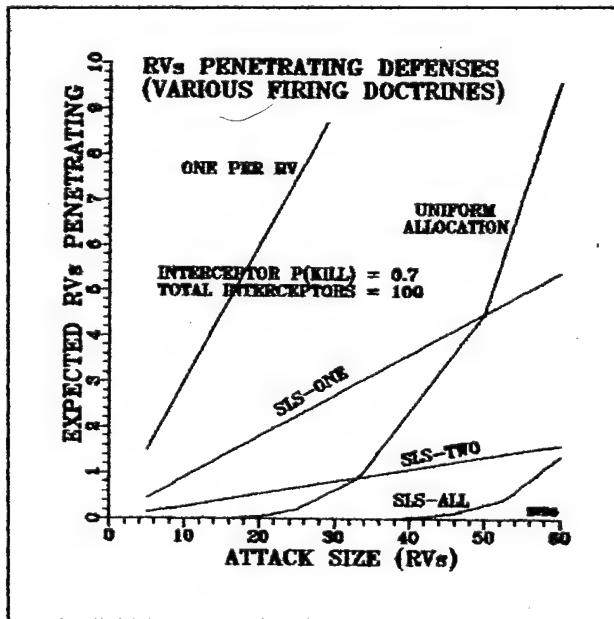


Figure 4

Decision makers may indicate that their objectives include complete negation of all small ballistic missile attacks. In this section, we assume that a national leader would accept a probability of 0.95 that there would be no RVs leaking through a ballistic missile defense. Under this criterion and with the limits on ABM interceptors in force under the ABM Treaty, not all attack sizes could be negated. Figure 5 indicates the number of interceptors

needed to counter various attack

sizes for a number of different SSPk values for a shoot-look-shoot defense campaign. The dashed line indicates the limitation of defenses to 100 interceptors. The defense could be forced to a uniform allocation of all interceptors if the battle space did not permit the conduct of a shoot-look-shoot campaign. Under these circumstances, many more interceptors would be needed to fend off small ballistic missile attacks.

What is the maximum attack size that could be countered with 100 ABM interceptors? The answer depends on the firing doctrine employed, the probability that no RVs leak through, the number of interceptors available, and the single shot probability of kill, SSPk. To provide some bounds on this problem, we assume that the probability that no RVs leak through the defense is set at 0.95, hopefully erring on the side of caution, and setting a value that national leadership might accept. The number of interceptors is set at 100 in compliance with present arms control treaties. Two uncertain parameters remain, SSPk and firing doctrine. The firing doctrine will always be an open question, and is dependent on the tactical situation prevailing at the time of employment of the defenses. The single shot probability of kill will almost always be uncertain, hopefully within some limiting bounds. At

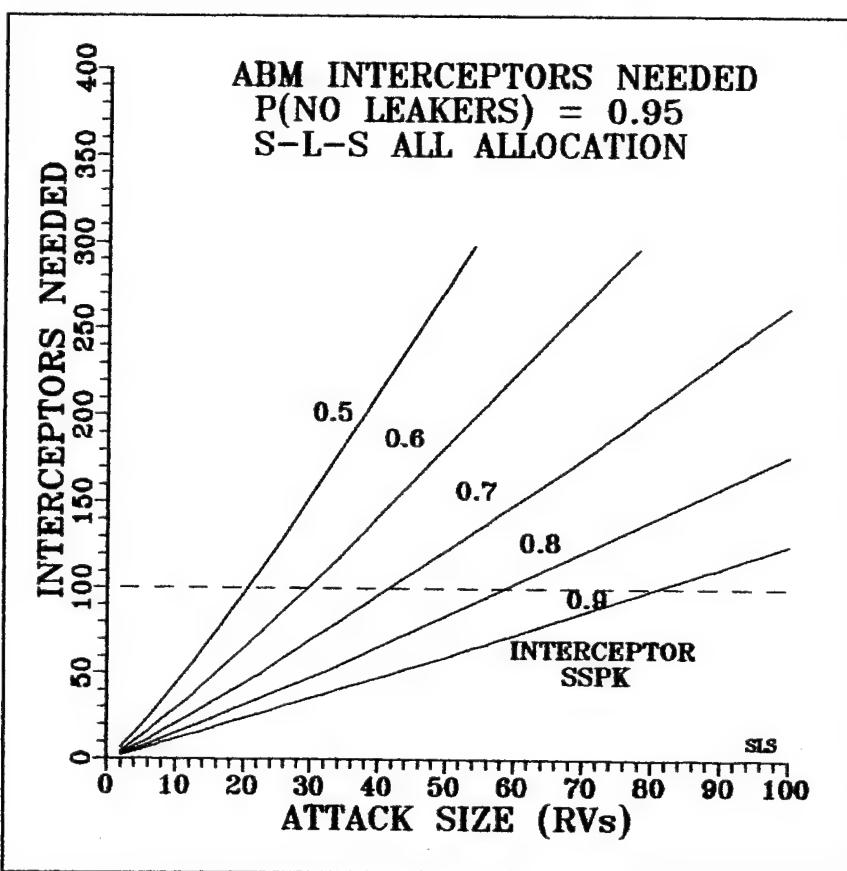


Figure 5

the present time, the SSPk for a ballistic missile defense system is very much undetermined, since no operational tests have begun to be made. With these uncertainties in mind, we now turn to find bounding values for a limited national defense against ballistic missiles.

The maximum defense capabilities for completely blocking small ballistic missile attacks are shown in Figure 6. The number of interceptors assumed is 100, and the probability that there will be no RVs leaking through the defense is set at 0.95. The results of two different firing doctrines are also shown. They are the shoot-look-shoot campaign where all interceptors are committed to counter an attack (SLS-ALL), and the uniform allocation of all

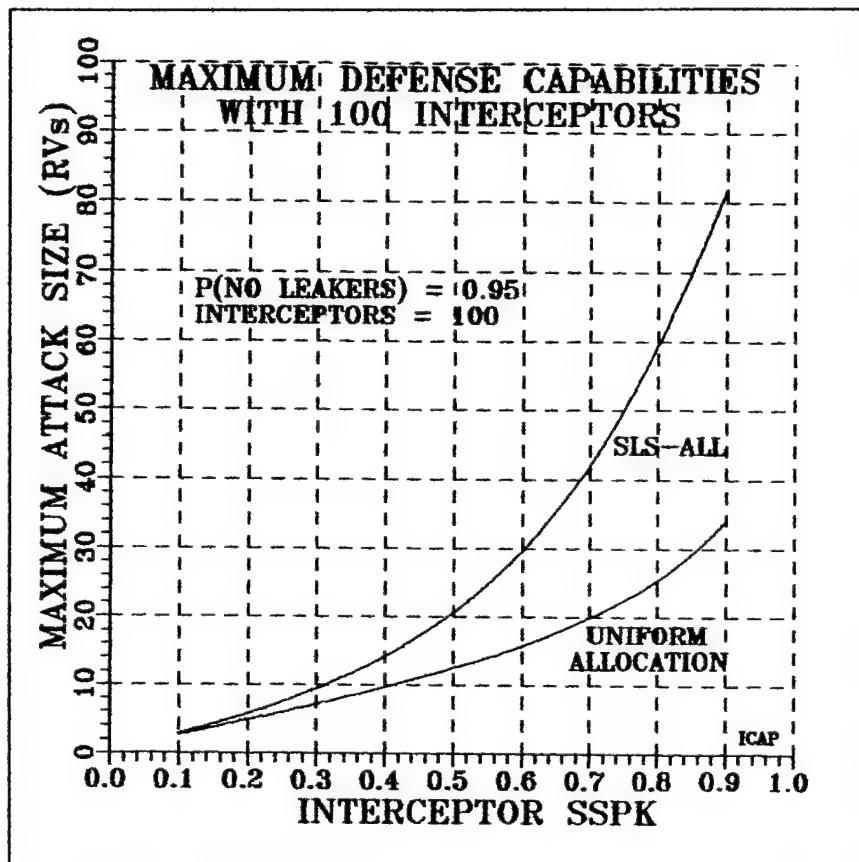


Figure 6

interceptors in salvos against all RVs. At low single shot probabilities of interceptor kill (SSPk), there is little difference between the two firing doctrines. A low value of SSPk across the interceptor force will permit countering only a very small attack, about three to seven RVs. If the interceptor SSPk is 0.5 or more, then the shoot-look-shoot campaign is clearly superior to a uniform allocation. For example, if the SSPk = 0.7, then an attack of 42 RVs could be countered in a shoot-look-shoot campaign. If there were no time for a shoot-look-shoot campaign, then a smaller attack of 20 RVs might be blocked when a uniform allocation of interceptors was employed. As the SSPk grows beyond 0.7, even larger differences in results between the two firing doctrines seem possible. If a national ballistic defense system can achieve an SSPk of about 0.5, then attacks between 12 and 20 RVs could be blocked with high confidence depending on the firing doctrine. On the more optimistic side,

assuming an SSPk of 0.8, attacks of 25 to 60 RVs might be countered with a confidence level of 0.95.

Recently, the United States Air Force examined the possible installation of twenty interceptors in Minuteman silos at Grand Forks Air Force Base in North Dakota. In this concept, Minuteman ICBMs would be converted into an interceptor role with conventional and homing warheads to intercept small ballistic missile attacks on the United States. The threats reported in the open literature included ballistic missile launches by North Korea and Libya. Such

interceptors would have an extremely long reach since they would be based on a three stage rocket [1]. Sensors discussed included the Defense Support Program and ground based sensors. The SSPk of such interceptors has not been determined. If the future threat of ballistic missile launches from these countries is small, then there might be a possibility that such a concept would be able to negate missile attacks. Figure 7 indicates the maximum threat that might be completely blocked with a confidence level of 0.95 as a function of the proposed interceptor SSPk. Two firing doctrines are indicated. Many of the same trends noted in Figure 6 above still hold even with this reduced interceptor stockpile. With an SSPk of 0.6, attacks of four to seven RVs (assuming no decoys) might be blocked with a confidence level of 0.95. On the very optimistic side, attacks of 8 to 17 RVs might be blocked if the SSPk were 0.9. If the threat from third world countries were within these bounds as suggested by one expert on future ballistic missile proliferation [2], then such a system would be considered as an effective defense of the U.S. homeland. If the SSPk of the system were about 0.3, then an

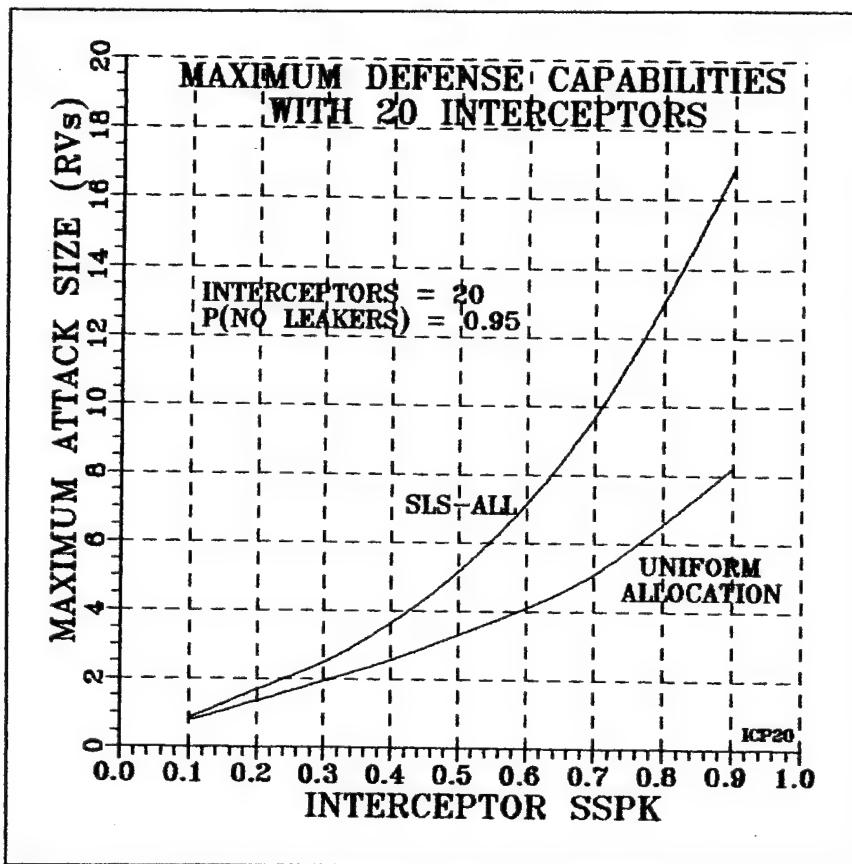


Figure 7

attack by one or two RVs could be countered. The reader is cautioned that such a system is but a concept, not an operational reality, and that threats of this magnitude may be less than those to be faced in the future. Nevertheless, this proposal has merit if very small attacks are projected within the time frame of the system development and deployment. Whether or not this proposed system would comply with the terms of the ABM Treaty [3] has yet to be determined. The ABM Treaty prohibits the upgrading of anti-aircraft interception systems' capabilities to provide defense against long range strategic ballistic missiles, but is silent about the use of ICBMs converted to this use, if they are designated as ABM interceptors and both parties agree. The conditions of Article VI and Agreed Statement D of the ABM Treaty would directly apply to this proposed use of ICBM rocketry to create ABM interceptor capabilities, in this author's opinion. Thus, the compliance with the ABM Treaty and the technical performance of the interceptors based on Minuteman ICBM technology will remain in doubt until a) discussions are held with the Russians, and b) testing is carried out to determine the performance of the Minuteman missiles as interceptors. If agreement is reached between the Russians and the U.S., then there may be a similar proposal to upgrade the present Moscow ABM system by replacing it with former Soviet ballistic missiles.

One feature of the Air Force proposal to use 20 Minuteman missiles as ABM interceptors is that not all of these interceptors need be expended to counter small threats. If the firing doctrine labeled SLS-SOME were employed, then this system could counter the threat of a few RVs, and still hold some interceptors in reserve.

There may be no need to salvo all interceptors to counter small attacks. The suggestion is that a high level of decision makers would specify a confidence level of providing that no RVs would leak through the missile defenses. As in previous discussions in this report, the probability of having no RVs leak through could be set to 0.95. Figure 8 indicates the number of interceptors needed to counter such attacks as a function of attack size. If the SSPk of the interceptors was 0.8, then the commitment of about 6 interceptors would more than meet the criterion for no leakers. If the SSPk were

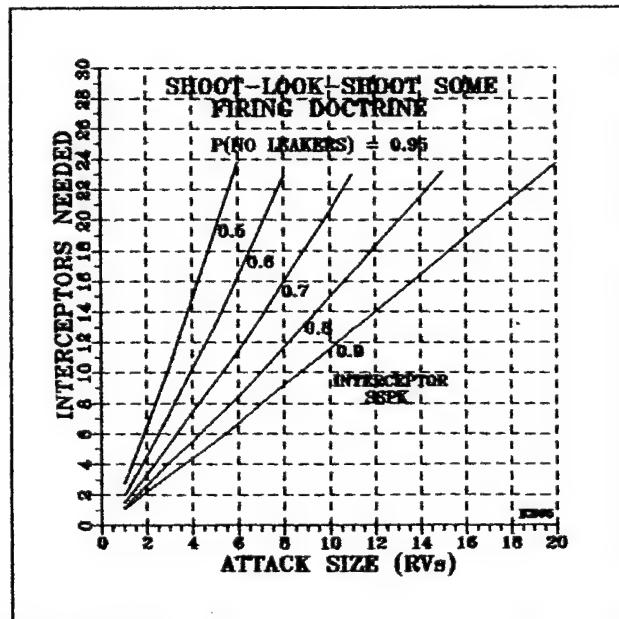


Figure 8

0.5, then about 15 interceptors would need to be committed to meet the condition that the probability of no RVs leaking through would be 0.95. In either case in these illustrative examples, not all of the interceptors would need to be committed, and some interceptors could be kept in reserve in case of follow-on attacks.

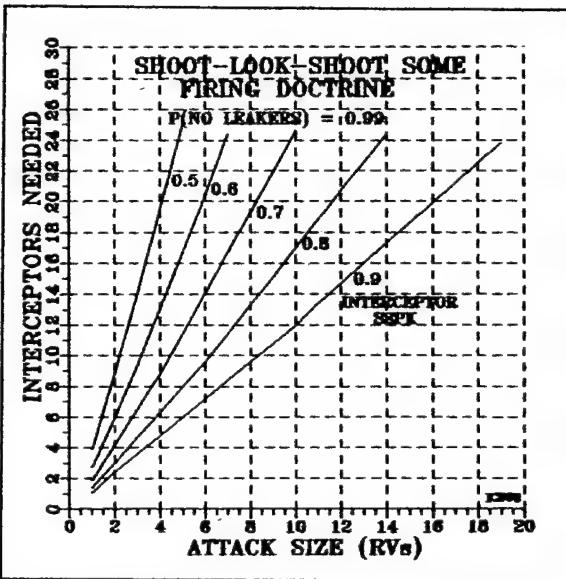


Figure 9

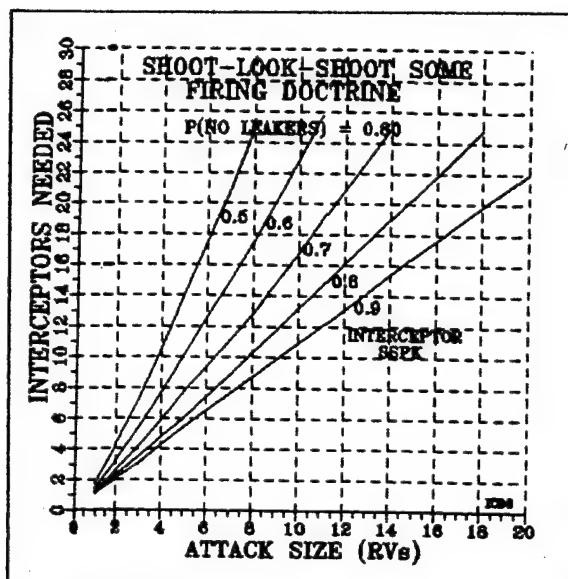


Figure 10

If the confidence level were to be lowered or raised, then more or less interceptors would need to be committed against small attacks. Figures 9 and 10 illustrate the variations should the confidence level be raised to 0.99 or lowered to 0.8. In either case, the number of interceptors committed is not much different from a confidence level of 0.95, IF the SSPk of the interceptors is high, about 0.9. At lower values of SSPk, the differences could be substantial. For example, if the attack consisted of 4 RVs and the SSPk were 0.5, then about 11 interceptors would be committed if the confidence level specified was 0.8. For a high confidence level, 0.99, about 20 interceptors would be committed to counter the same attack. The reader can supply other examples from these figures, so long as the SSPk achievable lies within the bounds used in this analysis.

From this analysis, it appears that the Air Force concept utilizing Minuteman ICBMs as ABM interceptors has merit for countering small attacks. The future threat may call for some changes. One such change would be to increase the number of interceptors if the perceived threat to the U.S. from the third world increases. With an inventory of 100 interceptors as an upper bound, the capabilities of such an ABM system could be used to counter not only third world threats, but also some accidental

launches originating from the future strategic forces of Russia. While one traditional threat of the "mad submarine commander" could amount to as many as 100 or 200 RVs, this possibility has been precluded by the reported installation of a permissive action link on Russian submarines. The lesser threats from Russia might consist of as many as nine RVs and their decoys launched from SS-25 (RS-12) ICBMs, i.e., ICBMs under the command of one officer. The possibility of Russian employment of credible decoys could raise questions as to the adequacy of the discrimination capabilities of U.S. sensor systems.

IV - LARGER BALLISTIC MISSILE ATTACKS

The purpose of this chapter is to provide the results of analyses which bear on the effects of large ballistic missile attacks on the U.S. In contrast to limited missile attacks, large attacks are defined as those in which the number of re-entering objects, RVs and decoys, would be greater than the 100 ballistic missile defense interceptors permitted under the ABM Treaty. This chapter presents the results of analyses which examine the effectiveness of different levels of ballistic missile defense capabilities with and without decoys accompanying the attacking re-entry vehicles. Two different methods of allocating defensive firepower, random subtractive defense and adaptive preferential defense will be compared in examples where the attacker uses decoys.

Large ballistic missile attacks on the U.S. could be the result of unfriendly relations with Russia, China, or emerging third world nations. Such attacks could include decoys that might replicate re-entry vehicles. With decoys, attacks from third world nations might overwhelm potential U.S. ballistic missile defenses, that is, the number of re-entering objects might be larger than the number of interceptors deployed. In these analyses, we examine the number of value targets that might be damaged with no defenses, with 100 interceptors allowed under the ABM Treaty, and with more interceptors should the ABM Treaty be amended. It is assumed that U.S. ballistic missile defenses would be deployed to protect value targets. Value targets are defined as targets which constitute power projection capabilities, and defense industrial capabilities. These targets are described here as amounting to 1600 aimpoints, and the value is assumed to be distributed according to the square root of the number of targets. In mathematical terms the value at risk is given by

$$9) V = T \cdot (n/T)^{1/2}$$

where T represents the number of targets, and n represents the number of weapons in the attack.

VALUE DAMAGED IN ATTACKS BY RE-ENTRY VEHICLES ONLY

Some attacks may consist of re-entry vehicles not accompanied by decoys. Under these conditions, the defense may choose to counter such attacks by allocating interceptors uniformly against the RVs so long as the interceptors outnumber the RVs. If the RVs are greater than the number of interceptors, then the defender allocates interceptors in a random subtractive defense doctrine. Under these circumstances the probability that the RVs will penetrate the defense is given by

$$10) P(\text{pen}) = 1 - k \cdot I/RV$$

where k is the SSP k of the interceptors, I is the number of interceptors available, and RV is the number of attacking re-entry vehicles.

The value damaged under these assumptions can be estimated for various levels of defense. In this example, we assume that the missile defense system has no capability (no interceptors), is limited to 100 interceptors, or has an expanded defense of 300 or 500 interceptors. Figure 11 shows the target value damaged as a function of attack size. With no defense and an attack size of 100 RVs, about 25% of the value of the U.S. target system would be damaged. With an attack of 400 RVs, about

half of the target system (1600 aimpoints) would be damaged. The implementation of a limited defense of 100 interceptors improves this situation. More interceptors lead to further reductions in damage. Even with 300 or 500 interceptors, substantial damage is inflicted when the attack consists of 500 RVs. In this figure, the interceptors are assumed to be allocated uniformly when the RVs are less than the number of interceptors.

VALUE DAMAGED IN ATTACKS WITH RVs AND DECOYS

The value of targets damaged will be increased when the attacker can employ credible decoys to accompany RVs in an attack. In this discussion, we assume that the decoy to RV ratio is two, and decoys will be allocated to accompany RVs according to the value of the target being attacked. The employment of an adaptive preferential defense will be considered and compared to the random subtractive defense doctrine as a function of the attack size.

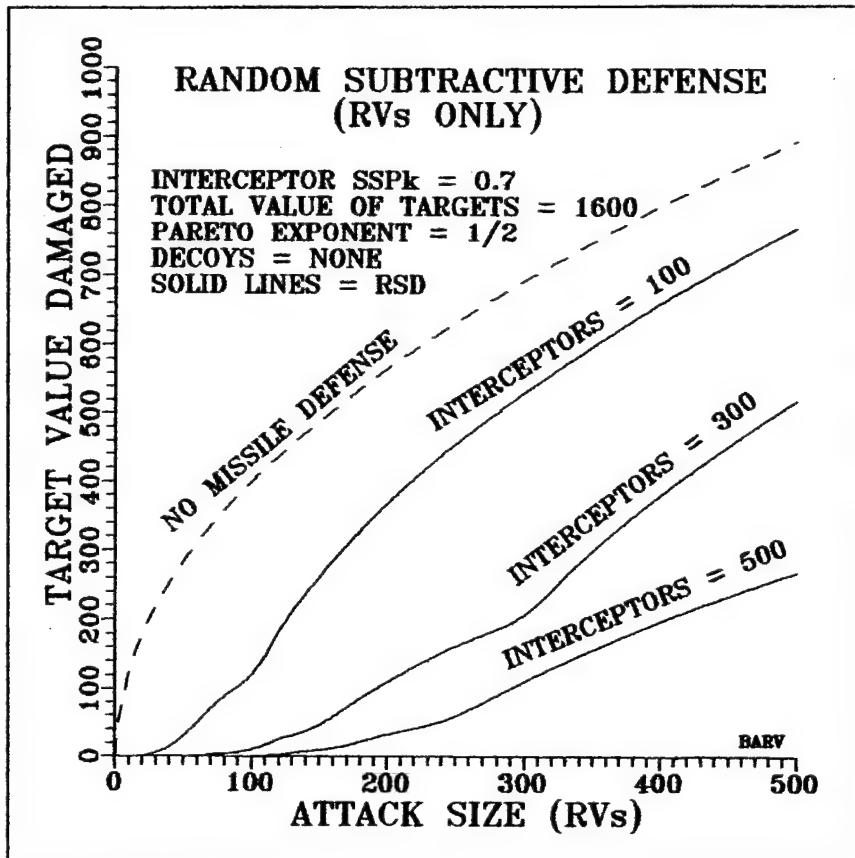


Figure 11

The introduction of decoys in attacks by RVs will lessen the effectiveness of ballistic missile defenses. If all targets were equally valued, then each RV would be accompanied by two decoys. Generally, all targets are not of equal value. In this analysis it is assumed that the value of targets follow a Pareto distribution with an exponent of 1/2. In addition it is assumed that the total value of U.S. targets being attacked is represented by 1600 aimpoints. Under such assumptions, RVs aimed at higher value targets would be accompanied by more decoys than those aimed at low value targets. One analyst [4] has suggested that the decoys should be allocated so that no matter what combination of one RV and its decoys are examined, the value saved by each interceptor would be equal. We follow this decoy allocation suggestion in the remainder of this analysis.

The attacker allocates decoys according to the value of each target. Each target is attacked by one RV plus decoys. To determine how many decoys would be sent, the value of each target is determined, in this case by examining the Pareto distribution of value one aimpoint at a time. Enough decoys are then assigned to each RV so that the value saved by the commitment of each interceptor is equal. If fractional decoys are admitted in the analysis, then the decoys are distributed to each RV in exact accordance with the allocation suggested. Fractional decoys are not possible in practice. Under these conditions integer rounding rules are varied so that the decoys exactly match the total number of decoys available. The value saved by each interceptor will vary somewhat from an ideal goal. When the defender runs out of decoys, then RVs would not be accompanied by any decoys, and the value saved by each interceptor in these instances would be lucrative targets if the defender employs an adaptive preferential defense. To determine which RVs are more lucrative objects for the defense, the entire attack must be observed by the defender's sensor system, and then interceptors would be allocated to these RVs. If the defender employs a random subtractive defense, then the entire attack need not be detected initially and commitment of interceptors would proceed as the attack unfolds.

To gain an appreciation of the effectiveness of the defense under various conditions, we offer one example. This example includes various attack sizes, up to 500 RVs with defenses varied from no interceptors to 500 interceptors. The target value damaged is shown as a function of attack size with the number of defense interceptors as a parameter. The single shot probability of kill (SSPk) is 0.7. Results are displayed in Figure 12. In this figure, higher values are damaged than in the previous figure where no decoys were assumed. The effect of defenses would be much less than shown in Figure 11. With decoys, the attacker may inflict unacceptable damage even with small attacks, less than 100 RVs if the defender is trying effectively to block

all damage to value targets. This trend holds for interceptor stockpiles of as many as 500 interceptors.

A comparison of random subtractive defense (RSD) and adaptive preferential defense (APD) is also displayed in Figure 12. The dashed lines indicate that the adaptive preferential defense would reduce damage to value targets, but only slightly as compared to the random subtractive defense doctrine. Since a slightly different allocation of decoys, or the addition of decoys aimed at targets but unaccompanied by RVs could upset the outcome of adaptive

preferential defense, we conclude that the use of a random subtractive defense model best represents the effect of defenses that is available at the present time. In the future, the details of the defense capabilities may become better known, and then such conclusions would need to be re-examined. For planning purposes, and for negotiations concerning ballistic missile defense at the present time, a random subtractive defense model offers an appropriate estimate of defense effectiveness.

Comparison of analysis results between attacks with and without decoys leads to additional observations. When decoys are sent with RVs, then the effectiveness of defenses is considerably diminished. From this result, the reader is cautioned that third world countries may be able to partially counter expanded national missile defense concepts even though such attacks may seem small in comparison to threats used for planning in the cold war era. From a perspective of a U.S. planner, indications of intentional development of decoys, or unintentional spreading of missile debris should be one focus of the intelligence community.

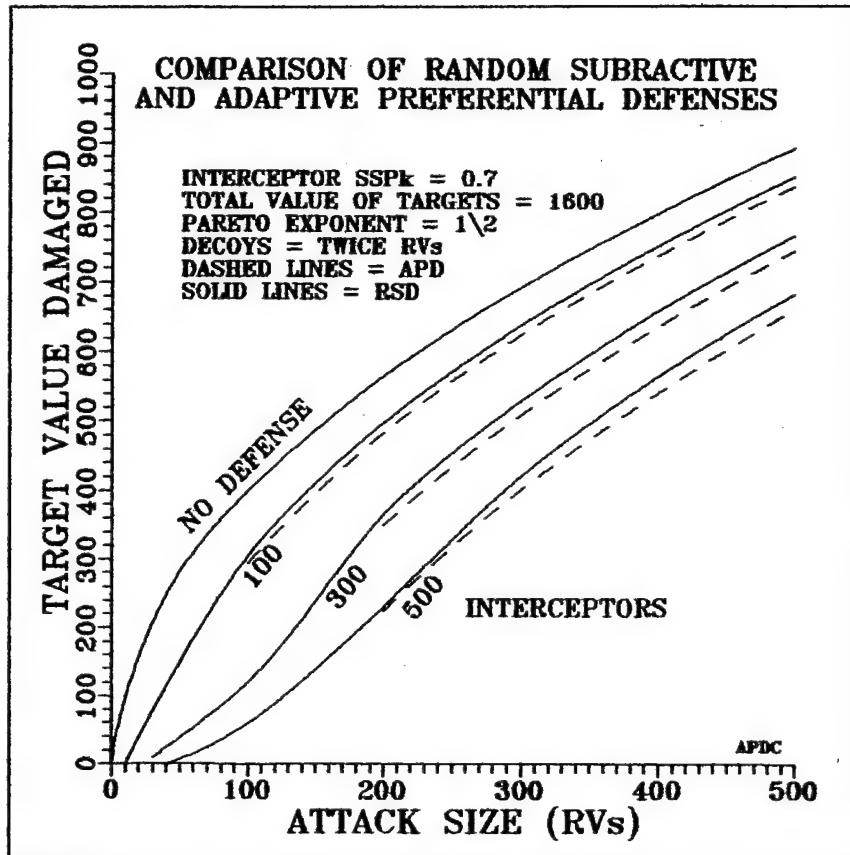


Figure 12

If the defender role were to be reversed, Russia defending against a U.S. attack, then U.S. planners would be remiss in not considering decoys as a counter to an extensive Russian deployment of ballistic missile defenses. The employment of decoys, instead of imitating Russia in deploying an expanded strategic defense, might serve as a more desirable alternative for the U.S. If the Russians were to deploy a ballistic missile defense, U.S. employment of decoys would degrade the effectiveness of a Russian system, would not degrade first strike stability appreciably [5], and might cost far less than the deployment of a national missile defense by the United States.

V - SUMMARY AND SOME IMPLICATIONS

Countering ballistic missile attacks on the United States while staying within the bounds of the ABM Treaty has been our major concern. The analytic focus of this report has been to examine methods of allocating ballistic missile defense resources to counter such attacks. This chapter is divided into two parts. The first part will provide a brief summary of the analytic approaches and some of their implications. The second part consists of observations that go beyond methodology. These observations have policy implications.

SUMMARY

The first part of this report presented analyses of how ballistic missile defense interceptors might be allocated to counter attacks when the stockpile of interceptors was greater than the number of attacking RVs. If battle space were very limited, the defender could be forced to uniformly allocate all interceptors against RVs in a single salvo. When battle space is not so severely limited, then the defender might be able to conduct a shoot-look-shoot campaign. The analyses examined here were limited to a two phase defense campaign where each RV was countered by one interceptor in the first phase. The "look" between interceptor commitments provided an assessment of which RVs were undamaged during the first round. This assessment was assumed to be perfect. Based on this assessment, interceptors were fired at the undamaged RVs. Variations on the second round were considered. The defender could fire all remaining interceptors (SLS-ALL), or could commit a lesser number of interceptors against each RV such as assigning two interceptors per RV (SLS-TWO), or allocating a single interceptor to each RV surviving the first round (SLS-ONE).

In a defense dominant environment, there could be a chance of negating all attacking RVs. Such a goal might be achieved with some level of confidence, provided enough interceptors were available. In this analysis, the number of interceptors needed to negate various attack sizes was determined for high confidence levels. The confidence level was defined as the probability that no RVs would leak through the defense. The analysis of the needed interceptors led to yet one more shoot-look-shoot firing doctrine. Under this doctrine, enough interceptors would be fired during the second round to provide high confidence that no RVs would leak through the defense, and any remaining interceptors would be kept in reserve in case further attacks were prosecuted.

Limited attacks could be dealt with using some of the allocation doctrines suggested earlier. Limited attacks are those where the re-entering objects are less than the number of defensive interceptors. Under the ABM Treaty, a maximum of 100

interceptors are allowed. Maximum attack sizes that could be blocked by 100 interceptors are highly dependent on the single shot probability of kill (SSPk) assumed for each interceptor, and are dependent on whether battle space limitations will permit a shoot-look-shoot campaign or not. If the SSPk of the interceptors were 0.5, then 21 RVs could be blocked if shoot-look-shoot campaigns could be prosecuted by the defender. If the battle space were limited so that all interceptors would need to be committed in a single salvo against all RVs (uniform allocation), then attacks of 12 RVs could be blocked. These results prevailed for a 95% confidence level that no RVs would leak through the defense.

Large attacks are those where the re-entering objects are greater than the number of defense interceptors. The re-entering objects could consist of decoys as well as RVs. Attacks with and without decoys were considered. Without decoys, ballistic missile defense substantially reduced the value of targets damaged compared to the case where no defense was deployed. If an attacker were to use twice as many decoys as RVs in an attack, then the effectiveness of a missile defense system limited to 100 interceptors was substantially degraded. Two different analytic approaches were examined in these examples: a random subtractive defense, and an adaptive preferential defense. The results obtained by either approach were nearly the same, in terms of damage inflicted on the defender's target base. Since the random subtractive defense model is much less dependent on the number of assumptions about the attack and the capabilities of the defense system, it is concluded that the random subtractive defense model represents the best approach for analyzing ballistic missile defense at the present time. If more details about future defense systems are made available at a later time, then this conclusion would need to be reviewed.

At present, the U.S. does not possess a ballistic missile defense system. Some might suggest that larger attack sizes might call for larger defense capabilities in terms of the number of interceptors. Larger numbers of defense interceptors were examined in the examples presented in this report. It is concluded that the effectiveness of larger defense systems can be substantially degraded by the use of decoys. Decoys provide an extremely effective leverage to the attacker, provided that the decoys are credible. Other analyses have shown that the decoys do not need to be perfect to affect defenses adversely in a negative fashion [5].

IMPLICATIONS FOR FUTURE MISSILE DEFENSE CONCEPTS

Some of the observations to be offered are dependent on the perceived threat of attack by ballistic missiles. Deterring such attacks has been the backbone of U.S. strategy for many decades. Some commentators on strategic doctrine [6] are lamenting the fact

that the U.S. does not now have a defense to ward off limited ballistic missile attacks by rogue nations who might not be deterred by the threat of nuclear urban renewal. This analysis has shown, if critical assumptions can be met, that a defense system consisting of 100 interceptors can block unsophisticated (no or few decoys) and limited ballistic missile attacks with high confidence.

A defense system with 100 interceptors or less could be developed and deployed within the terms of the ABM Treaty. Would such a defense system cope with the present or future threat to the U.S.? The U.S. has relied on deterrence to counter threats of massive attack by major nuclear powers in the past. Present strategic doctrine of the U.S. seems to have measured up to such threats. Threats of accidental attacks originating in military elements of major nuclear protagonists, or threats directed against the U.S. by rogue nations would be limited. Reasonably capable interceptors, although limited in number to 100 or less, should provide protection against such threats. A concise review of such threats under future conditions is available in the open literature. This review concluded that under START II the realistic ballistic missile threat levels would be limited. "Consequently, most remaining accidental or unauthorized attacks after 2003 will likely contain fewer than 10 warheads, with perhaps as many as 50-100 large objects if advanced decoys are deployed. Third countries are not likely to develop large ICBM arsenals, much less SLBMs or MIRVed ICBMs, for some time. Hence, attacks from these countries will probably involve fewer than 10 warheads. The debate about possible attack sizes will ultimately revolve around the number and types of decoys an adversary might deploy, as well as on the ability of the defense to discriminate decoys from actual warheads."^[2]

This analysis has indicated that the capabilities needed to counter the threats outlined in the above review might be sufficient. This collection of analyses has shown that small stockpiles of interceptors could deal effectively with limited attacks by ballistic missiles. The location of interceptor bases, their range, and the effectiveness of sensor and command and control systems supporting their commitment would be important factors. Some of these factors are yet to be resolved, as illustrated by inclusion in this report of the U.S. Air Force concept of using former Minuteman ICBMs as interceptors as one example of the application of these analyses. This exemplary concept provides long range interceptors that could protect assets distant from the interceptor base such as Hawaii and Washington, DC, if sensor and accurate tracking coverage can be provided along with appropriate command and control arrangements to assure timely commitment of interceptor assets. No matter what concept seems attractive, the technical aspects of the probability of interceptor success in countering incoming RVs remains to be validated. These aspects involve the details of

acquiring the attacking RVs, determination of trajectory parameters, providing timely warning for potential launch opportunities, and then assuring that the interceptor guidance systems have sufficient data to assure a reasonable probability of damaging each RV.

To provide an overview of the capabilities that would be needed to counter the threats outlined above, one figure in this report is reproduced here. Figure 13 shows that threats from third world nations, including the present Chinese ICBM force of 17+ missiles [7] could be countered with high confidence within a limit of 100 interceptors, even though the interceptor single shot probability of kill might be low. The addition of decoys could present

difficulties for any U.S. anti-ballistic system limited to 100 interceptors. In Figure 13 detection and discrimination sensors are assumed to be able to sort out which objects are RVs and which are decoys with high confidence. Two interceptor firing doctrines are indicated. If attack warning and tracking data can be assembled well ahead of time, a shoot-look-shoot doctrine could enable 100 interceptors to counter many RVs. If shorter warning and track assembly times prevail, then a uniform allocation would have to serve. Under such constraints, it appears that attacks limited to ten or twenty RVs could be countered with 100 interceptors. For pessimistic appraisals of interceptor single shot probability of kill as low as 0.10, attacks of three or four RVs could be blocked, if all 100 interceptors were launched and provided with accurate information concerning the trajectories of the attacking re-entry vehicles.

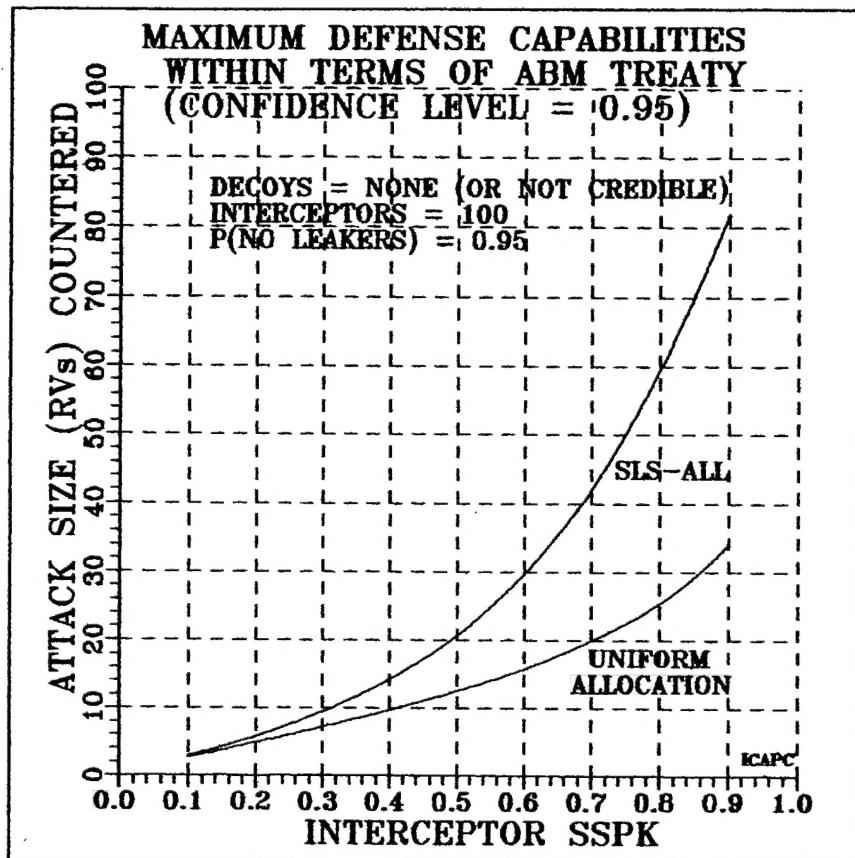


Figure 13

Blocking ballistic missile attacks with 100 interceptors located at a single base could pose problems. The reach of interceptors would have to be considerable, more than those envisioned in terminal defense system concepts. Uncertainties abound, particularly with regard to the probability of damage and the accuracy of determining which RVs were damaged in the first round of interceptor commitment. The range of single shot probabilities of interceptor kill shown in Figure 13 seem to span most of the potential values possible. Yet to be demonstrated is the actual value that might be achieved in practice.

The challenge for the designers and developers of a national missile defense system remains to meet those goals that lie within the criteria set by the terms of the ABM Treaty, the national command authority, national goals in foreign policy, and future decisions concerning arms control and disarmament. Issues having a bearing on these decisions include future plans for missile defense, negotiations with potential protagonists, the magnitude of the ballistic missile threat from major nuclear and lesser powers, and budgetary limitations. How some of these issues will change or evolve in the future may not be clear at this time. In spite of uncertainty in such high level issues, it would be appropriate for planners to examine and formulate concepts that comply with the ABM Treaty, that is, those which are ground based and limited to 100 interceptors at a single site. Limited attacks by rogue nations or accidental missile launches could be met by effective ballistic missile defenses limited to 100 ABM interceptors.

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